MODELING AND ANALYSIS OF AF DEPOT BUSINESS PRACTICES FOR SUPPLY

THESIS

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AFIT/OR/MS/ENS/12-03

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THESIS

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MODELING AND ANALYSIS OF AF DEPOT BUSINESS PRACTICES FOR SUPPLY

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Abstract

This thesis explored the impact of heroic actions on depot maintenance operations in terms of aircraft flow days through programmed depot maintenance and in terms of lost production hours. In an era of fiscal uncertainty and reducing budgets, an understanding of the impact of heroic actions would lead to efficiency gains for the Air Force. Depots do not routinely report the associated impact of heroic actions on their operations and recent efforts to assess these impacts have not arrived to a definitive conclusion.

To assess the impact of heroic actions on depot processes, a discrete event simulation was developed for the KC-135 depot operations and heroic actions. Two scenarios were developed and relative impact of heroics was assessed. A baseline case was created with the intent to model current operations and an alternate scenario was developed based on the premise that additional funds for part procurement would reduce the flow day and production hour impact of heroics. An analysis of these scenarios shows that reducing the frequency of heroic actions does significantly impact KC-135 flow days and lost production hours.

Dedication

For my wife, without you this would not have been possible. I love you.

Acknowledgments

I am greatly indebted to my faculty advisor, Dr J.O. Miller, for his patient guidance throughout this process. He provided the flexibility that allowed me to make this thesis my own, while offering insight and encouragement.

I am also thankful for the support of the management of the Manufacturing Technology Division of the Materials and Manufacturing Directorate of the Air Force Research Laboratory. Thank you for making this a possibility, without you this would definitely have not been possible.

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MODELING AND ANALYSIS OF AF DEPOT BUSINESS PRACTICES FOR SUPPLY

I. Introduction

1.1 Background

A key aspect of the Air Force's ability to accomplish its mission, "to fly, fight and win… in air space and cyberspace", is the ability to sustain its war fighting equipment. To manage this need, the AF has established three Air Logistics Centers or Depots to execute the maintenance and overhaul activities for its entire fleet of aircraft. The dynamic environment of these facilities is due to the desire to execute maintenance operations with both "speed and quality" (Schanz, 2011) commiserate with the expectations of its chief customer, the warfighter. These requirements drive a careful ballet that occurs on a daily basis to continually improve production processes and manage parts demand, forecasting and availability on the shop floor.

Parts are supplied to the depots from several sources. The Defense Logistics Agency (DLA) supplies consumable items for all services, and over 109,000 parts for the Air Force (Towell, 2011). A consumable item is an item that when found defective on a weapons system is simply replaced and not repaired. The Global Logistics Support Center (GLSC) is responsible for Air Force supply management of items that are repaired when found defective, or reparables. Some smaller portion of parts is supplied by maintenance contractors directly, outside of DLA and GLSC operations. The coordination of each of these sources by depot staff is required to

ensure that parts are available to maintenance personnel when needed during Programmed Depot Maintenance (PDM).

The reality on the depot line is that parts are not always available to maintenance personnel when needed to complete a task. The unavailability of parts will cause a delay in aircraft delivery to the field and result in further scrutiny from field managers and increased pressure on depot leadership. To avoid these negative outcomes, the maintenance personnel seek to satisfy the demand for the unavailable component outside the normal parts supply processes and procedures. These actions are referred to as heroics, which represent the additional burden the depot undertakes to deliver the aircraft in a timely manner.

1.2 Problem Statement

Today, the need for heroics in meeting maintenance demand for parts at AF depots is likely due to efforts to reduce the cost of inventory and adoption of ‘just in time’ principles for inventory management. These principles drive parts acquisition managers to avoid large procurements of hard to find or long lead time items and leads to a ‘procurement on need’ mentality. The need for heroics, and subsequent negative impact on the maintenance organization, are not included in the total inventory costs use to plan parts purchases. The cost of heroic actions and their impact on ‘optimal’ procurement practices is not well understood.

Figure 1 shows a notional plot of the ‘Cost of Inventory’ and the ‘Cost of Parts Chasing & Waiting’, or heroics. This plot indicates that there may be some optimal point that minimizes the total cost of chosen inventory levels to the Air Force based on inventory costs and the associated need for heroic actions. This research focuses on modeling and analyzing Depot

business practices that characterize the heroics cost curve and their relationship with inventory planning.

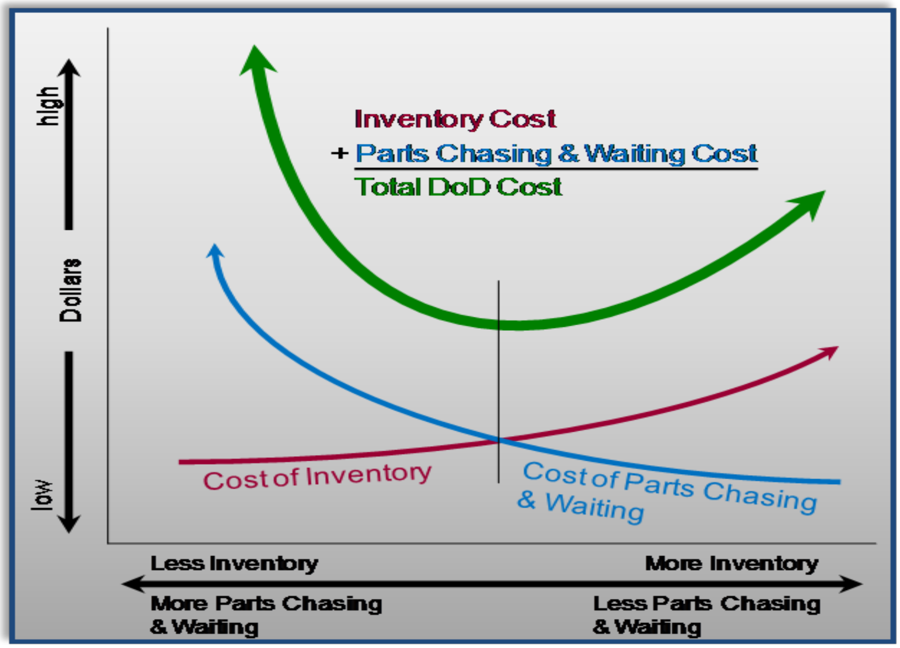

Figure 1: Cost of 'Heroics' Diagram (Gehret, 2011)

1.3 Research Scope

The impact of heroics on depot operations is a complex issue with elements of production labor time, equipment usage rates, engineering overheard, procurement specialist labor and many other unnamed elements. This thesis will focus on the development of a model for the quantification of the impact of heroic actions on depot operations in terms of aircraft flow days and cost. The model developed will specifically include the heroic actions that impact the Structures Build Up (SBUP) phase of PDM for the KC-135.

1.4 Approach

This effort seeks to first, quantify the impact of heroics in terms of lost or inefficient labor time over several procurement scenarios and secondly, to use the lost hours in a calculation of the overall cost of these actions at the depot. A discrete event simulation (DES) will be used to generate the lost or inefficient hour data. The available data does not enable an analytical assessment of the costs associated with heroics and a DES provides a reasonable means to obtain that data for calculation.

Using discrete event simulation is also useful for analyzing various model alternatives. In this effort a baseline case and alternate scenario are developed and assessed. The ability to assess multiple scenarios based on inventory levels enables an initial assessment of the 'Cost of Parts Chasing & Waiting' curve, shown in Figure 1.

1.5 Thesis Outline

The remaining topics covered in this thesis are broken out into four distinct chapters. Chapter II covers a review of heroic actions, description of the KC-135 depot operations and a discussion regarding the most relevant sources related to the impact of heroics in a maintenance environment in the open literature. Chapter III describes the development of a model for analysis of the impact of heroics, covering conceptual model development, Arena implementation and input data analysis. Chapter IV presents the basic results and analysis executed using the model, including the analysis of an alternate inventory management scenario. Chapter V covers the final conclusions and recommendations for future work in the study of the impact of heroics on depot operations.

II. Literature Review

2.1 Overview

As part of the modeling process a review of available literature and sources for analyzing the impact of heroics on depot operations was executed. Several basic topics were explored, including; a description and definition of the varying types of heroic actions, a background on KC-135 and published literature on the subject of alternate supply mechanisms for maintenance operations. The most relevant findings are summarized in the subsequent sections of this chapter.

2.2 Description of Heroic Actions

The definition of heroics is not found in a Technical Order or Operating Instruction. For the purposes of this paper, heroics were defined as actions taken whenever the demand for an item, consumable or reparable, was satisfied through means other than the normal supply chain or procurement process. Individual heroic acts can be classified as one of eight identified actions discussed briefly in the following sections. These descriptions were developed with support from many organizations within program offices and maintenance wings.

A depot cannibalization is the removal of a fieldable component from one aircraft on the depot maintenance line and reinstalling the removed component into another aircraft for use. The depot often makes efforts to consolidate the ‘holes’ that remain when a part is cannibalized onto one aircraft. This operation requires the replacement cost to double, due to the subsequent reinstallation of the proper component into the aircraft that was cannibalized. Typical cost

elements for a depot cannibalization would include the mechanics time removing the component from the cannibalized aircraft and then reinstalling the same component on the same aircraft. Another commonly used term for depot cannibalization is ‘CANN’.

An AMARG cannibalization is the removal of a fieldable component from an aircraft within the 309th Aerospace Maintenance and Regeneration Group (AMARG) at Davis-Monthan Air Force Base (AFB) and reinstalling the removed component into another aircraft at the Depot to satisfy component demand. The AMARG is a storage facility for retired DoD aircraft. At the request of a program office or maintenance wing, the AMARG will cannibalize an aircraft at Davis-Monthan AFB and ship it to the depot for installation. Typical cost elements for an AMARG cannibalization would include the cost of AMARG technicians to remove the component, shipping costs and the cost of the depot to inspect and certify the component for use. Another commonly used term for AMARG cannibalization is ‘AMARG pull’.

A lateral supply is the transfer of a component from one location to another to satisfy maintenance demand for that component. These actions take a variety of forms; from one base to another, from one aircraft line to another within the same depot or from backshop to backshop within the same depot. Line to line and backshop to backshop laterals are informal actions and are not tracked regularly. Base to base transfers of components are more defined processes which involve multiple organizations. Such an action is often managed by the DLA or GLSC with support from program office and wing level engineering. Typical cost elements include engineering/management overhead and shipping.

An emergency buy is a procurement process used to obtain parts for maintenance demand from an alternative supplier. Such a purchase may consist of surplus parts owned by private parties or newly manufactured components, typically in small lots, when a current contract’s

terms will not satisfy depot demand. Parts purchased via emergency buy processes are typically orders of magnitude more expensive than components purchased on planned regular procurements. Typical cost elements include increased unit part cost, procurement specialist's time and engineering/management overhead. Another commonly used term for this type of action is 'gap buy'.

Depot manufacturing is the use of organic manufacturing capability to satisfy maintenance demand for components. Depot manufacturing resources are used when a part cannot be purchased from the supplier base or lead time/cost considerations of supplier offers makes purchasing the item a less favorable option. Typical cost elements include repair material, production labor, engineering/management overhead and production equipment time.

A non-economical repair is a repair where the repair cost of parts and labor exceeds 75% of the replacement cost of parts and labor. OC-ALC/GKC OI 21-109 defines an economical repair as "a repair where the repair cost of parts and labor does not exceed 75% of the replacement cost of parts and labor." A non-economical repair is ordered when parts are not available to replace the item and it is repaired even though it does not meet the threshold as a reparable item. Typical cost elements include repair material, production labor, engineering/management overhead and production equipment time.

A deferral action delays a maintenance action until a subsequent PDM/overhaul cycle due to lack of components to service the aircraft or sub assembly. Typical cost elements include program office engineers for tracking and approval, management overhead and potential for degraded weapon system capability or failure.

A field installation is a maintenance action that is delayed and scheduled as a field operation. Parts are then delivered to the field, when available, for service. Typical cost

elements include field technician’s labor, management overhead and potential for degraded weapon system capability.

2.3 KC-135 Programmed Depot Maintenance

The KC-135 Stratotanker, originally produced by The Boeing Company, provides the Department of Defense with an aerial refueling capability, supporting the Air Force, Navy, Marine Corps and allied nations’ aircraft (Perez, 2012). The aircraft can transfer up to 200,000 lbs of fuel through its boom to receiving aircraft (see Figure 2 for photo) and is one of the oldest active aircraft in the Air Force inventory with over 50 years of service. The Air Mobility Command currently manages an inventory of 414 KC-135s in various configurations.

Figure 2: KC-135 Refueling F-15 (Perez, 2012)

The warfighter, in conjunction with the Tanker Program Office, looks to the maintenance wing at Tinker AFB to maintain the active fleet of KC-135 aircraft. Every 60 months these aircraft go through a full PDM cycle to ensure the aircraft are safe and mission capable (Farris, 2012). As these aircraft age, the depots are asked to process an increasing number of aircraft through PDM each year, rising from 48 aircraft in FY08 to a projected 64 aircraft in FY12. To execute this task a team of over 1300 personnel, from both the production flight and weapon system support flight, are involved.

Over the past decade the KC-135 production system has undergone several major changes from a three piece flow concept in 2002, two piece flow in 2005, the single line concept in 2008 and to the current configuration, in 2009, with the staggered line concept (Farris, 2012). The staggered line concept has enabled the depot to reduce flow days from on average 224 days per aircraft to 128 days in early 2012.

The staggered line concept for KC-135 depot operations is divided into five production stations, as depicted in Figure 3. The entry point to the depot is called Pre-Dock and is where the aircraft paint is stripped and washed down (Farris, 2012). This process takes between 10-12 days to complete. After washing is complete, the aircraft is moved to I-Dock for pre production inspections and some light inspections related to boom and landing gear refurbishment. This station consists of five docks and takes between 15 and 17 days to complete. The inspections that take place here form the basis for the negotiated bill of materials between the maintenance wing and program office. Each aircraft has a pre existing bill of materials for the planned PDM work, but during I-Dock inspections unanticipated maintenance requirements often present themselves. Once the inspections are complete, a full maintenance package and bill of materials is established and the aircraft then proceeds to the Structures Build Up (SBUP) station.

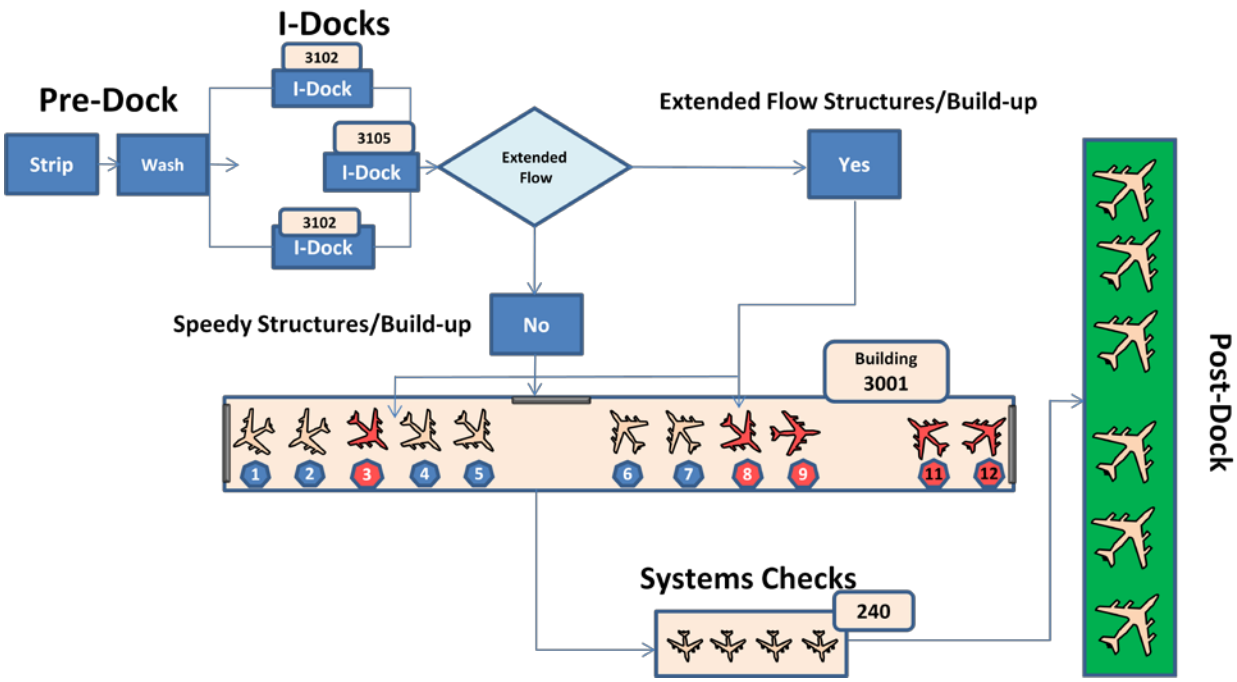

Figure 3: KC-135 PDM Flow Diagram (Farris, 2012)

SBUP is where the majority of heavy maintenance occurs at the depot for the KC-135. This is the station where windows are replaced, electronics are refurbished, the engines are reinstalled, wing tips are repaired etc. In all, there are about 26 major jobs that occur at this phase in the PDM operation (Schatz, 2012). SBUP is where the staggered line concept derives its name. Here the aircraft are designated either extended flow or regular. Extended flow aircraft are those that are anticipated to have a longer maintenance cycle time in SBUP based on data collected during the I-Dock inspections. Extended flow aircraft are given positions in docks 8, 9, 11 or 12 of the total docks in SBUP (Farris, 2012). Positioning the extended flow aircraft in these docks minimizes the incidence of blocking regular flow aircraft in their docks, preventing them from proceeding to the next station, Systems Check.

Systems Check is where various pre flight inspections occur to verify that the aircraft systems are functioning properly after SBUP. This station is divided into 5 docks and takes between 13 and 20 days to complete (Farris, 2012). Once all checks are complete, the aircraft is moved to Post-Dock for repainting, refueling and engine checks. This occurs on six dedicated docks and takes between 24 and 47 days.

In total the KC-135 depot maintenance operation uses 18 docks, with an average of 22 aircraft in process, to execute PDM on time and on cost (Farris, 2012). In FY11 the maintenance wing exceeded customer expectations by processing 64 aircraft through PDM, crushing the 58 aircraft target. The maintenance wing has been embarking on a focused effort to bring KC-135 PDM flow day average to 130 days since March 2009. As part of this initiative over 300 rapid improvement events have been executed, an enterprise value stream map for KC-135 was developed and a constraint buster team was established for working tough, short fuse activities. The recent progress toward their goal of a 130 day flow time is a testament to the team's dedication and perseverance.

2.4 Relevant Published Literature

A literature review was conducted to determine what aspects of Heroics have been examined and to what extent modeling and simulation had been used as a tool to quantify Heroics. In general, the broad issue of actions similar to Heroics was not well documented among the publications and presentations available, while individual aspects of it, such as cannibalization policy, were covered in depth. The majority of prior work omits a rigorous quantification of the impact of Heroics in any manner, instead focusing on demand

forecasting/scheduling and procurement process improvements to meet part demand. These topics are important; addressing the issue of parts availability and potentially reducing the need for Heroics. When quantification of the impact of Heroics was attempted, it was determined by speculative means and left out critical elements that contribute to the total cost of executing a Heroic action. The most relevant publications are summarized below.

In August 2011 AFMC Commander General Hoffman issued a formal suspense, via AFMC/A4, for data regarding the cost of line stoppages caused by parts shortage at each of the Depots ("Bullet Background paper on Cost of Line Stoppage Caused by Parts Shortages", 2011). This request was generated in a discussion of ways to increase efficiencies within depot operations. Among the specific actions and considerations to be investigated included "flow days, CAP waivers, CANNs, job routing" etc. Most of these are references to heroic actions as defined in section 2.2; 'CANNs' refers to AMARG and depot cannibalizations, 'CAP waivers' refers to depot and field deferrals and 'job routing' refers to local manufacture and non-economical repair actions. The formal response from the Depots to AFMC contained a mix of quantitative and qualitative data; a summary of the quantitative data (for FY11 to date) is shown in Table 1. Qualitatively the report points out that the actions referenced above can cause production delays and do increase costs at the depot. The Depots also assert that "Without more detailed logistics decision support system capabilities, this effort is currently more art than science…" ("Bullet Background paper on Cost of Line Stoppage Caused by Parts Shortages", 2011).

The lone attempt found to quantify the impact of Heroics in open literature, in any terms (cost, man-hours, count, etc.), was outlined in a publication titled 'The Lean Value Chain for

Critical Part Procurement' (Painter, 2002). This effort was primarily focused on reducing the time to identify and resolve "critical part needs" (Painter, 2002). Painter defined a critical part as

Table 1: Quantitative Input to AFMC Data Call ("Bullet Background paper on Cost of Line Stoppage Caused by Parts Shortages", 2011)

Cost Factors	OC-ALC	OO-ALC	WR-ALC
Overtime (OT) for CANN and Rob (non job-routed part) Actions	$0.8M	Data pending*	$1.0M
Customer Support Buys Necessary due to Supply System Non-delivery	$2.2M (combination of AF and DLA-managed parts)	Data pending*	Data pending*
Local Manufacture Necessary due to Supply System Non-delivery	$1.7M	Data pending*	Data pending*
Standby (Idle Worker) Costs	Data pending*	$5.0M	Data pending*

*Centers responded differently to the open data call; a standardized response is in work.

"any part whose anticipated or actual lack of availability will prevent on-time completion of the weapon system maintenance, repair and overhaul (MRO) process". According to Painter's definition, a critical part would be a part that has the identified potential to require a Heroic action. An attempt to quantify the impact of the Lean Value Chain effort was made by estimating the labor hours spent by mechanics chasing parts via a survey of the mechanics themselves. The survey indicated that mechanics spend up to 3 hours per day chasing parts after implementation of the Lean Value Chain software solution.

Gill (2011), Chief of the 76^{th} MXW Transformation at Tinker AFB, executed an analysis of parts that received no-bids during the procurement process. No-bids occur when the government solicitation for a part does not receive any quotes or bidders. This issue is of particular concern for aging aircraft where the original parts suppliers no longer exist or cannot produce the part at a cost deemed to be reasonable by procurement authorities. Gill's analysis attempted to estimate what price the DLA should be willing to pay for the part in order to fulfill the depot's demand for the part. The report's findings indicated that the government could offer up to 500% of current book prices for hard to procure components with a minimal impact on total cost of procured parts for the KC-135. By the author's admission, this analysis was not widely accepted by the depot or DLA community and did not influence parts procurement processes. While details of this study were not entirely clear as they were presented, the report did not attempt to incorporate the cost of Heroic actions as part of the cost the government would be willing to pay for a part or the quantity ordered.

In a different effort, Fisher and Brennan (1986) present a comparison of several varying cannibalization policy's performance in aircraft maintenance operations. The authors describe a discrete event simulation based on a SLAM software package with spares, repair operations and resource constraints. The comparison was based on backorder level and consisted of policies that ranged from no cannibalizations to cannibalize every time there is an opportunity. Backorder level, in this context, was used to note aircraft that were waiting on parts. The different policies created an 18% difference in backorder level from the 'worst' policy to the 'best'. This work provides a basis for use of simulation in analysis of Heroic actions, but focuses solely on cannibalization leaving out many other alternatives to supply a part via Heroics during depot operations.

Other publications related to the simulation of AF depot operations include an AFIT thesis on analysis of B-1 High Velocity Maintenance (HVM) (Yee, 2011). This effort identified supply factors that affected the HVM process. HVM for the B-1 had not been fully implemented when this analysis occurred. Of special note for this thesis was the use of modeling and simulation when detailed data did not exist. Another AFIT thesis (Shyong, 2002), used simulation to evaluate the impact of changes to logistics support plans and schedules in reducing depot maintenance cycle times and work in process levels for the F101 low pressure turbine rotor.

This literature review presents the available thoughts and ideas behind prior work related to heroics. Individual actions have been thoroughly examined (Fisher & Brennan, 1986), while their aggregate effect has not been established. Prior efforts to quantify cost of heroics have relied heavily on an interview process (Painter, 2000) or ignored certain critical elements of the cost of a heroic action (Gill, 2011). From this review it can be concluded that a quantitative analysis of the aggregate impact of heroic actions has not be definitively undertaken.

2.5 Summary

The manifestation of heroic actions is caused by the inability of the current procurement process to satisfy 100% of the demand for components generated by maintenance operations. In this chapter, an understanding and definition of the various heroic actions that depot operators may encounter and utilize was identified, a background on the KC-135 and standard depot processes was established and a review of open literature has shown evidence that modeling and simulation is a plausible means for assessing the impact of heroic action on depot processes. The

next chapter will detail the construction of a simulation used to assess the impact of heroics on depot operations.

III. Methodology

3.1 Overview

This chapter details the conceptual model and development of the simulation created during this effort. This simulation was developed to incorporate elements of depot production, the need for heroic actions and their interaction at the depot. To assess the impact of heroics on depot maintenance operations a baseline model was developed, which reflected the system current state, as well as a comparison model developed based on an assumed increase in part procurement efficiency or increased spare parts budget. A description of the conceptual model presented was largely developed using information received during discussions with KC-135 maintenance staff. The baseline and comparison simulations are thoroughly discussed along with the development of the input data for these models.

3.2 Conceptual Model Development and Description

As part of the preparation for the development of a simulation to determine the impact of heroic actions on depot processes, a conceptual model was developed. This model, shown as Figure 4, was developed based on interactions with KC-135 engineering staff and 654th maintenance staff. The intent was to capture the generation of part demand through depot operations, general inventory levels, the supply of parts to include both heroic and the normal procurement processes and how/where these processes interact. This model was used as a basis for abstracting the real system into Arena.

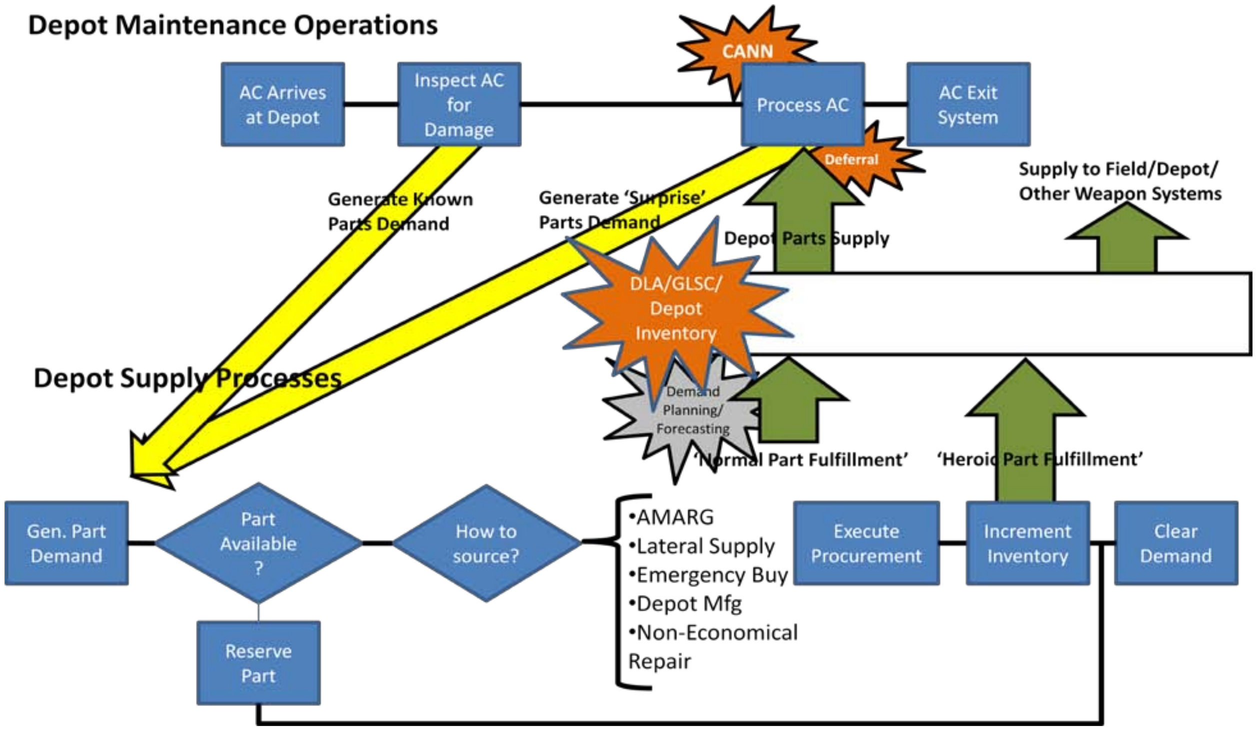

Figure 4: Conceptual Model

Heroics become an issue on the maintenance floor when the current parts supply process is not able to meet current demand generated by depot operations. Depot operations are described in this model as four distinct sections; arrival at the depot, inspecting the aircraft, executing the required PDM actions, and the aircraft leaving the system. After arrival, each aircraft was inspected for damage that would be above and beyond the regular PDM package. After this step was completed for a given aircraft, the bill of materials for that aircraft is negotiated between the aircraft program office and the wing. This activity is noted as the lighter arrow labeled as 'Generate Known Parts Demand' in Figure 4. The bill of materials highlights parts that are required to complete the maintenance which are not in the current inventory. If a part is not currently available, the procurement options are listed and a course of action chosen.

The program office and wing staff could choose to wait for a planned delivery of parts from a contracted source or choose to execute one or more of the heroic actions described in Chapter II. Once the part is procured through whatever method chosen, the part is placed in inventory and is then available to the shop floor for use.

Once the bill of materials is generated and sent to signal the need for a procurement decision, the aircraft moves to the 'Process AC' section. This section represents the entire portion of mechanical work on the aircraft. It is anticipated that if parts are not available in inventory as part of the normal fulfillment process or a heroic one, there will be a delay in processing the aircraft. There are also several heroic actions noted as part of this section; depot cannibalization, depot deferral and field deferral. These actions are noted here because they are not procurement processes in the manner that procurement is usually considered. While these actions effectively 'generate' a part for use during maintenance, they do not actually make a new part available. Cannibalization removes a part from another aircraft on the maintenance floor. Depot and field deferrals are actions taken that extend the life of the part on the aircraft for a length of time determined by an inspection plan established by wing and program office engineers. Another interesting action that occurs in this section of the conceptual flow is that new component demand is established (see lighter arrow labeled 'Generate 'Surprise' Parts Demand' in Figure 4) on occasion. Depot staff stated that most components that need replacement are identified during the 'Inspect AC for Damage' section, however, there are cases when a defective part is not identified until later in the aircraft processing section, as captured in this conceptual model.

Once all required parts are procured and all maintenance actions are complete, the aircraft leaves the depot and returns to service.

3.3 Model Assumptions

Using the conceptual model previously outlined, a simulation of the impact of heroics was developed for this effort. Several assumptions were made in the leap from conceptual model to Arena simulation based on limitations in available data or for ease of implementation in Arena. These assumptions are listed below.

- Only parts that require a heroic action to fulfill a demand are modeled. The contracting processes for normal part procurement and supply are not explicitly modeled.

- Only heroic actions that are required to complete a process in the SBUP dock are modeled. Most of the actions that were present in the available data could be linked to SBUP and subject matter experts from the wing supported the exclusion of heroic actions linked to other PDM docks.

- The conceptual model (discussed in section 3.2) asserted that component demand was primarily generated after I-Dock and some new component requirements would develop in later PDM phases. For this simulation, demand generated during later PDM phases is not explicitly modeled, but is included with demand generated after I-Dock inspections.

- Each sub process in SBUP consists of a base processing time and an unknown delay until all required parts supplied through modeled heroic actions are available.

- No explicit manpower resources are modeled.

- This model only incorporates the flow days impact of four heroic actions of the eight previously identified: depot cannibalization, AMARG, emergency buy and lateral support. Data

was not available for building a model that incorporated deferral actions, field installations, non-economical repair and depot manufacturing.

3.4 Baseline Discrete Event Simulation

Using the conceptual model outlined in section 3.2 and the assumptions listed in section 3.3, a simulation was developed in Arena. This section outlines the development of this model. The baseline model for assessing the impact of heroic actions on depot maintenance operations was divided into two major subsections: depot maintenance operations and heroic actions for component supply.

3.4.1 KC-135 Programmed Depot Maintenance Model

The depot maintenance operations in this discrete even simulation follow the general flow shown in Figure 5 below.

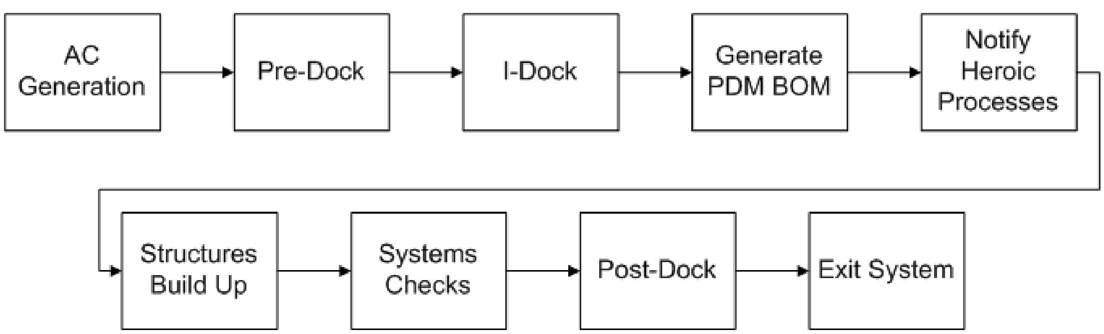

Figure 5: Simulation Process Flow

The first section of the model, 'AC Generation', was where each aircraft entity was generated and assigned several initial identifying attributes. Each entity was assigned a unique

tail number used for tracking needed parts in the system. This portion of the model was implemented using an Arena create and assign module. Aircraft entities arrived at a constant rate of one every six days. This data was provided by the KC-135 master scheduler, who plans and tracks aircraft arrivals to the depot.

Pre-Dock was modeled by a simple delay with no resource requirements for the process. Typically this operation is not a processing constraint and capacity is not a concern. I-Dock was modeled by a process module with capacity restricted by the number of available docks at the depot. These docks were modeled as resources and required to complete the I-Dock portion of the model.

As in actual depot operations, the Bill of Materials (BOM) to process an aircraft through PDM is generated after I-Dock in the 'Generate PDM BOM' section of the model. The Arena implementation of this process is shown in Figure 6. In the first assign block counter attributes are assigned for use in processing in the 'Notify Heroic Process' section of the model. The next four assign blocks determine the number of heroic actions that are required to process the aircraft entity through the PDM operations. The number of each action was determined by an input distribution developed based on actual data provided by DLA and KC-135 Program Office personnel, over an approximately 12 month period. For AMARG pull each aircraft entity is assigned a value for the number of actions that it requires to process through each sub process in the SBUP phase (frequency distributions and SBUP sub process break down described in detail in subsequent paragraphs). The value is stored in a two dimensional variable, *AMARG(i,j)*, where the row index is the assigned tail number and the column index is the SBUP sub process number. This setup is duplicated for assigning lateral supply and emergency buy requirements. For example, an aircraft entity with tail number set to 14 may be assigned a requirement for one

AMARG cannibalization, one emergency buy and zero lateral support for sub process 1. This would correspond to $AMARG(14,1) = 1$, $EBuy(14,1) = 1$ and $Lateral(14,1) = 0$.

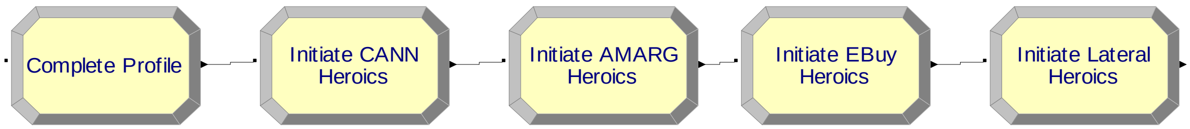

Figure 6: Arena Implementation of 'Generate PDM BOM'

Depot cannibalizations were handled differently than the other three heroic actions in this model. Each aircraft entity is assigned two values for the number of cannibalizations that it requires to complete processing: one for parts that the aircraft needs and one for parts that are given away to other aircraft. This logic intentionally did not explicitly pair specific tail numbers for receiving or losing parts, but accounts for the delay involved for an aircraft undergoing either type of action. These values are based on distributions developed from data provided by the maintenance wing at Tinker AFB. Data was available only for the tail number needing the part to be cannibalized with no information given regarding the frequency of an aircraft losing a part during a cannibalization action. We therefore used the same distributions, with independent random number draws for received and donated parts for each aircraft, for each SBUP sub process. The cannibalization values were stored in a two dimensional variable, $CANN(i,j)$, where i is the assigned tail number and j one through six, are the values for needing a part though SBUP sub process one through six and j seven though twelve are the values for losing a part though SBUP sub process one through six.

The next group of Arena modules, 'Notify Heroic Processes' shown in Figure 7, was where the processes for executing AMARG cannibalization, lateral supply and emergency buys

were notified (through a signal in Arena) of a component demand to be satisfied by that heroic process. The logic for the heroic processes is discussed in section 3.4.2.

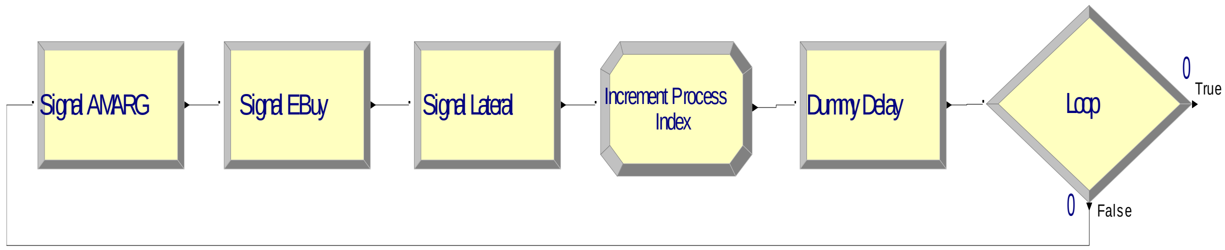

Figure 7: Arena Implementation for 'Notify Heroic Processes'

The aircraft entity processes through this loop for the number of sub processes in the model (six). When an entity enters the loop it triggers the release signals (first three modules in Figure 7) for the required AMARG cannibalizations, emergency buys and lateral supplies for the first process. These signals trigger the release of entities from their hold modules in the heroic action process logic, to be discussed later. The process index is incremented and when the process increment is greater than six, the entity leaves the loop.

SBUP was broken down into sub processes based on a work break-down structure (WBS) that was provided by the KC-135 maintenance wing at Tinker AFB. Processes were grouped based on their approximate timing in the process flow. Processes that roughly occurred simultaneously with a critical path task were rolled into a single sub process for our simulation as shown in Figure 8. Here 24 tasks on the KC-135 WBS were consolidated to 6 sub processes for

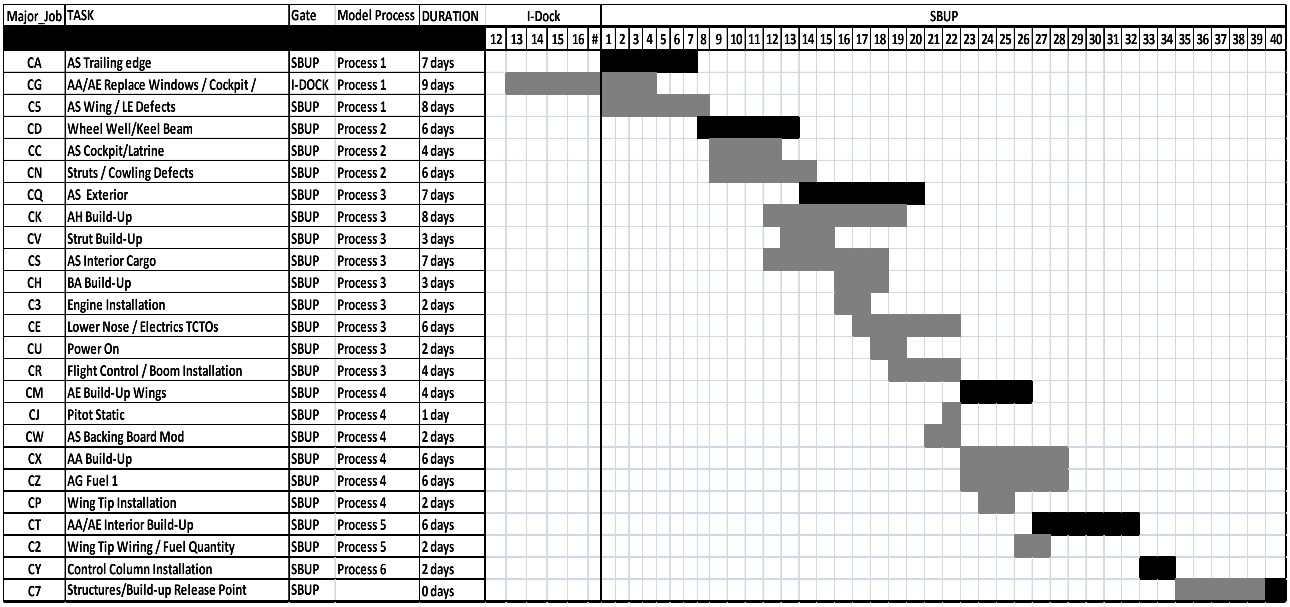

Figure 8: KC-135 SBUP Sub Process Breakdown

our model. This breakdown was vetted by wing staff and determined to be reasonable since most of the dependencies within this WBS followed the critical path tasks (highlighted in black on Figure 8).

System Checks and Post Dock were modeled in a similar manner as I-Dock with capacity restricted by number of available docks.

3.4.2 Heroic Actions Process

The heroic parts fulfillment process flow for AMARG cannibalization, lateral supply and emergency buy were implemented in Arena using a separate entity flow for each type of heroic action as displayed as Figure 9.

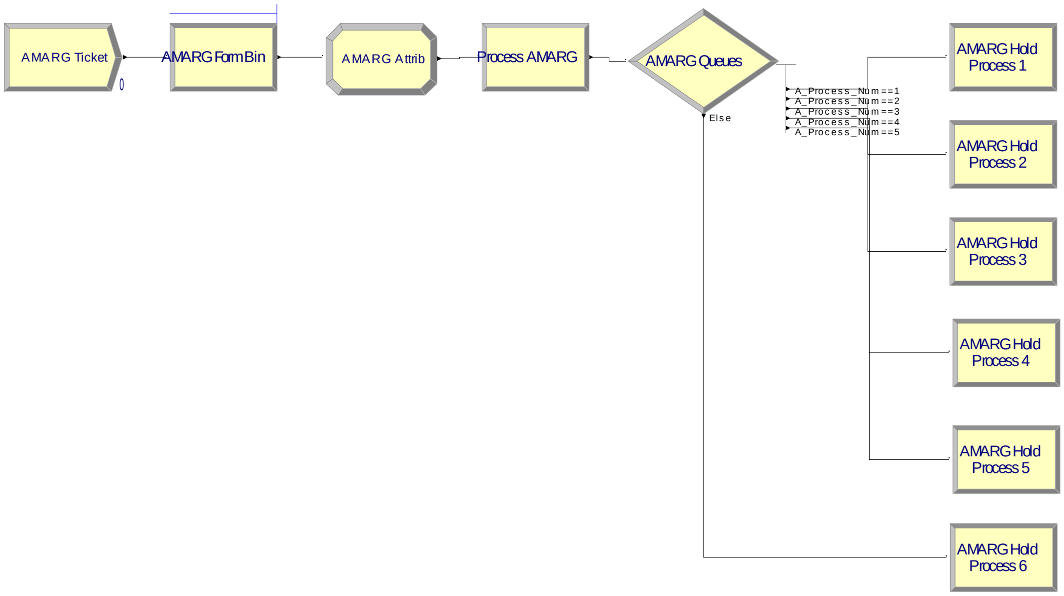

Figure 9: Heroic Parts Fulfillment Arena Implementation

At the beginning of each simulation replication 1000 heroic action entities are created and placed in a hold module using parallel logic for AMARG cannibalization, lateral supply, and emergency buy processes (AMARG shown in Figure 9). The entities are released from the hold module upon receipt of the appropriate signal, per the logic in the 'Notify Heroic Processes' loop (see Figure 7), and sent for assignment designation. Each heroic action entity represents an individual part obtained through that heroic action required by a specific aircraft tail number at a particular SBUP process. The heroic action entities are then sent through a delay module, which represents the delay time for processing the action from initial request to part delivery and subsequent availability on shop floor. After processing is complete (the part is available to the maintenance operation), the heroic action entity is sent to a queue specified by tail number and SBUP process. For example, if aircraft entity 17 required 3 AMARG pulls to complete sub process 1, each of the three heroic action entities, upon completion of processing would be sent

to the queue titled ‘AMARG Process 1 Tail 17’. The number in each assigned queue represents the number of parts available from each heroic action for use by the assigned aircraft tail number and sub process. This value is evaluated by the appropriate aircraft tail number at the appropriate sub process as a condition to proceed to the next sub process or on to System Check.

Because of the different logic used to generate depot cannibalizations as discussed in section 3.4.1, cannibalization fulfillment did not require an explicit delay to wait for a part as did the other three modeled heroic actions. Therefore the cannibalization fulfillment logic is captured in the circled loop shown in Figure 10 based upon the number of assigned cannibalization actions for that tail number, for each of the six sub processes of SBUP. The wait block following this loop in Figure 10 captures all the associated delays for the other modeled heroic actions. Each of the six sub processes in SBUP follows this same logic, with the last sup process flowing into systems check.

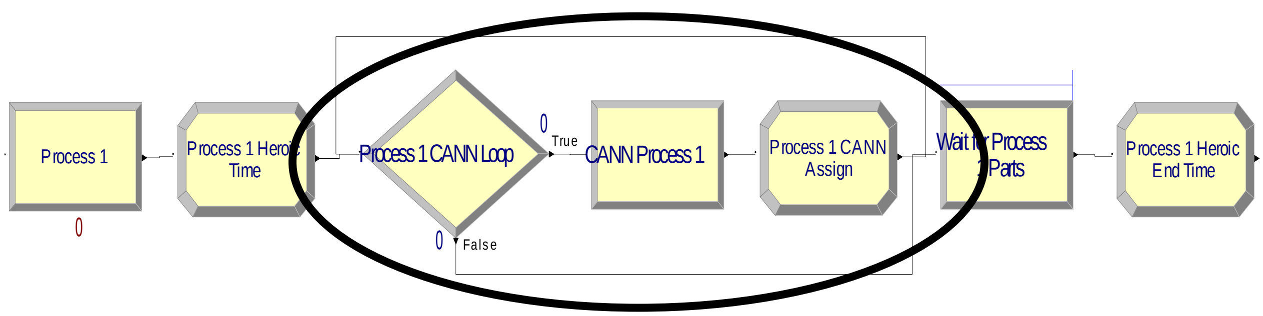

Figure 10: Arena Implementation of Depot Cannibalization Delay

3.5 Input Data

Data described in Section 3.4 was obtained from various sources for input into the model. The following sections describe the methodology for obtaining the data and transforming it for useful input for the model.

3.5.1 Depot Operations Process Times

Process cycle time data for Pre Dock, I-Dock, Systems Check and Post Dock was provided by the 564th AMXS in a presentation titled “564 AMXS Way Ahead” briefed by Ms Theresa Farris (Farris, 2012). The briefing provided dock level cycle times for the prior ten aircraft to pass through that phase. Since the data was extremely limited, a formal input analysis method using Arena Input Analyzer was not used. Instead a quick look was taken, noting the minimum value, maximum data and the value that appeared to occur most frequently. These values were used to create triangular process cycle time distributions for the four processes modeled at the dock level. SBUP was included in the prior data set, but another method was used as described in the following paragraphs. The final input distributions or constants are shown in Table 2.

SBUP was broken down in the model to six sub processes. An investigation into how cycle time data was collected at the depot during PDM indicated that reliable data at the major job level was not available. So an alternate method for obtaining input data had to be developed. The WBS, provided by the 564th AMXS, shown in Figure 8, included a column for nominal job time and a task designated as schedule buffer to reflect occasions when the actual cycle time was greater than the planning number. It was assumed (and deemed reasonable by the 564th AMXS) that the planning number for major job cycle time consisted of the anticipated time to complete the job with some consideration of manufacturing task variation. It was also assumed (and similarly validated) that that planning time did not include process delays due to unavailable parts and that any delay due to parts availability issues could be added to the planning number

Table 2: Depot PDM Cycle Time Input

	Distribution	Units
Pre Dock	TRIA()	Days
I-Dock	TRIA()	Days
Structures Build Up		Days
Process 1	8	Days
Process 2	7	Days
Process 3	9	Days
Process 4	8	Days
Process 5	6	Days
Process 6	2	Days
Systems Check	TRIA()	Days
Post Dock	TRIA()	Days
TRIA – Expression pulls values from a triangular distribution with the given parameters		

and be used as a reasonable estimate for actual cycle time. Based on these assumptions, the planning cycle time numbers for the rolled up SBUP major jobs were used as the modeled cycle times for the six sub processes.

3.5.2 Heroic Action Process Times

Data recording instances of heroic actions was primarily found in logs, maintained by individual and disparate groups at the wing. Depot cannibalization data and AMARG cannibalization data was obtained from records kept by the Tanker Production Support Group (564^{th} AMXS/MXDXAB). The data for depot cannibalizations for the KC-135 was broken down by action date, part number, national stock number (NSN), part name, source of supply

and gaining aircraft tail number. Installation and removal hours were also provided in the data, but review of these numbers revealed that most of them were input as '0.1' hours. This was the negotiated rate that the 564th AMXS can charge the KC-135 Program office for depot cannibalizations and was not an accurate reflection of the real time it takes to remove and install a cannibalized component (Kaminski, 2011). No other source of data was found that reliably captured the time to process a depot cannibalization, so subject matter expertise from the 564th AMXS/MXPAA was elicited to develop the distribution recorded in Table 3.

Table 3: Heroic Action Cycle Time Input

	Distribution	**Units**
Depot Cannibalization	UNIF(.5, 8)	Hours
AMARG Cannibalization	TRIA(30, 35, 45)	Days
Lateral Supply	UNIF(3, 5)	Days
Emergency Buy	TRIA(,)	Days
TRIA – Expression pulls values from a triangular distribution with the given parameters		
UNIF – Expression pulls values from a uniform distribution with the given parameters		

The subject matter expert reasoned that cannibalizing a component can take a short amount of time, approximately half an hour, but that the wing would not cannibalize a component that would take longer than a shift (8 hours) to remove (Rayner, 2012). These values were used as the minimum and maximum values for a uniform distribution since there was no other information available to support any other input for the model.

The data for AMARG cannibalizations for the KC-135 was broken down by request date, NSN, part name and quantity. The logs provided by the Tanker Support Group lacked several key pieces of information; tail number and received date. Since no received date was recorded a distribution for AMARG processing/delivery times could not be developed empirically. As with depot cannibalization, subject matter expertise was elicited (Palacios, 2012) for the distribution of processing/delivery times for parts supplied through the AMARG. The subject matter expert was able to provide a minimum, maximum and most frequently observed delivery time for input as a triangular distribution. The final distribution for input was recorded in Table 3.

Lateral supply and emergency buy logs were provided by the DLA KC-135 Support office (DLA Aviation/QAAEXAA). The logs for lateral support actions were broken down by request date, NSN, Base Code, part description and quantity. Again, these logs lacked data with a tail number and received date. As with the prior actions, subject matter expertise was elicited (Rayner, 2012) for the distribution of processing/delivery times for parts supplied through lateral support. The subject matter experts were able to provide a minimum, maximum and most frequently observed delivery time for input as a triangular distribution. The final distribution for input was recorded in Table 3.

The logs for emergency buy actions were broken down by request date, received date, NSN, part number, part description and quantity. Again, these logs lacked data with a tail number but a received date field was available for analysis! The fulfillment time was used as input into the Arena Input Analyzer software. The initial software recommendation was a gamma distribution with a p value of 0.22. Since the gamma distribution was only bounded $[0, \infty]$, a triangular distribution was selected as the final input. The final distribution for input was recorded in Table 3.

3.5.3 Heroic Action Frequency Distributions

The data logs, briefly outlined in section 3.5.2, were used to develop aircraft profiles which specified the number of each heroic action that each entity would require to complete each of the six sub processes in SBUP. The building of these profiles was implemented in Arena using assign modules (see Figure 6). To construct the dataset for a frequency distribution of each action per sub process, several different pieces of data were used.

The logs provided by the DLA and 564th AMXS staff did not include which process the specified part was required for. To link each part to a depot process each NSN needed to be matched with a 'major job' code. This code is used to designate each task level operation at the depot. A key that linked major job code to each task (and further, model sub process) was also required. To address these needs, a bill of materials for the KC-135 was provided that contained each NSN and its associated major job code. The NSNs from the logs were formatted, in Excel, to match the NSN format of the NSNs in the bill of materials. Then a simple lookup command, based on NSN, was used to pull in the major job code into the log data set. Since the log data was entered by hand, there were many instances of mistyped NSNs that did not find a match in the bill of materials data set. When this occurred, the data was reviewed manually, attempting to reasonable match the log data to a bill of materials NSN. There were many times where this process was successful in reconciling the data and there were others where it was not. When a reasonable match was not found between the two data sets, the log line item was omitted from the final data set.

Once each log line item had been matched to a major job code, the WBS provided by wing staff was used to match major job codes to tasks under the WBS. This was accomplished in Excel using a similar approach as described previously. After matching each log entry with a major job code, the log entry was matched with the appropriate model sub process. This completes the method for building the data sets to include the depot task and useful incorporation into the described model.

As stated previously, for AMARG cannibalizations, lateral support and emergency buy actions there was no tail number provided in the logs to support an explicit per aircraft analysis. But when the total count for these three actions was broken down by sub process, the average per aircraft was less than one. To simplify the analysis, it was assumed that each aircraft could only have a maximum of one of these actions per sub process. This enabled the development of a discrete probability distribution on a per process level given that 64 aircraft passed through the depot during the FY11 data collection period. A sample calculation for AMARG cannibalization is provided in Table 4.

Table 4: Sample Frequency Distribution Calculation

Sub Process	Count of AMARG Cannibalization	Probability of 1 Action	Distribution
Process 1	2	0.03	DISC(.97, 0, 1,1)
Process 2	0	0.00	0
Process 3	3	0.04	DISC(.96, 0, 1, 1)
Process 4	3	0.04	DISC(.96, 0, 1, 1)
Process 5	5	0.08	DISC(.92, 0, 1)
Process 6	0	0.00	0
DISC – Expression pulls values from a discrete distribution with given parameters			

In this example, the count of AMARG cannibalizations was divided by the assumed number of aircraft passing through the system (64) for the probability of each aircraft requiring an AMARG action for each process. A similar approach is used for lateral supply and emergency buy actions. The full set of distributions per process for each of these actions is provided in Table 5.

Table 5: Heroic Action Frequency Distributions

	Depot Cannibalization	**AMARG Cannibalization**	**Lateral Support**	**Emergency Buy**
Process 1	DISC(.45, 0, .69, 1, .83, 2, .94, 3, .98, 4, 1, 5)	DISC(.97, 0, 1,1)	DISC(.81, 0, 1, 1)	DISC(.87, 0, 1, 1)
Process 2	-	-	DISC(.94, 0, 1, 1)	-
Process 3	DISC(.09, 0, .28, 1, .53, 2, .69, 3, .8, 4, .84, 5, .97, 6, 1, 7)	DISC(.96, 0, 1, 1)	DISC(.54, 0, 1, 1)	DISC(.78, 0, 1, 1)
Process 4	DISC(.3, 0, .55, 1, .75, 2, .89, 3, .98, 4, 1, 5)	DISC(.96, 0, 1, 1)	DISC(.91, 0, 1, 1)	DISC(.98, 0, 1, 1)
Process 5	-	DISC(.92, 0, 1)	DISC(.46, 0, 1, 1)	DISC(.83, 0, 1, 1)
Process 6	-	-	-	DISC(.98, 0, 1, 1)
DISC – Expression pulls values from a discrete distribution with given parameters				

Depot cannibalization logs did provide a tail number for use in developing frequency distributions for each process. A sample calculation for Depot cannibalization for sub process 1 is provided in Table 6.

The number of cannibalizations per aircraft were tallied and recorded in the 'Frequency' column in Table 6. Since aircraft with zero cannibalizations were not included in the data set, 64 was used as the nominal number of aircraft that went through the depot and used to calculate the

frequency value for zero occurrences. The 'Frequency' tally was divided by 64 for the probability of that tally. A discrete distribution was then developed from the probabilities and the tally they represented. The same process was used for the development of the remaining sub process distributions for depot cannibalizations.

Table 6: Depot Cannibalization Frequency Distribution Sample Calculation

Sub Process	Count	Frequency	Probability	Distribution
Process 1	0	29	0.45	DISC(.45, 0, .69, 1, .83, 2, .94, 3, .98, 4, 1, 5)
	1	15	0.24	
	2	9	0.14	
	3	7	0.11	
	4	3	0.04	
	5	1	0.02	
DISC – Expression pulls values from a discrete distribution with given parameters				

3.6 Verification and Validation

To ensure that this model functioned as intended a phased modeling approach was used. First a simple system with one sub process and one heroic action was constructed with constant numbers of the action assigned to each entity. Variable displays were placed on the Arena workspace for visual verification that the entities were functioning properly within the system (i.e. waiting for the right parts before exiting). Primary variables used in the observation exercise were the number of heroic actions required to complete processing for the first entity and the number of heroic actions which have completed processing for that entity.

The next phase was the development of a system with one sub process and the four heroic actions that were to be in the full and final model. The use of variable displays was also the

primary means of verifying that the model was functioning properly. This process was used again for the transition to a model with multiple sub processes and multiple heroic actions. This step by step process with each phase including more and more complexity made verifying the function of the model simple and reduced the amount of trouble shooting required on the model with full complexity.

Key measures of the model output were also identified and collected as statistics within the model. Aircraft PDM cycle time and average number of aircraft in process were statistics collected for validation purposes. These values compared favorably with data supplied by the program office (section 4.3 details this comparison).

In addition to statistics collected for validation, statistics were also collected to obtain an estimate of the number of production hours lost due to heroic actions. These statistics were collected using assign modules throughout the process flow. Data on how much time was lost over a given time frame due to heroic action was not available from the depots and would be useful for assessing the impact of heroics on depot operations in terms of aircraft flow days and as a surrogate for the cost of these actions.

3.7 Development of Comparison System

An alternate scenario was developed to assess the impact of additional funding for spare parts or for the benefits of an improved procurement method. One way of doing this is to modify the input data of the model, rerun the model and compare the collected data with the baseline model. To accomplish this, the heroic action data from section 3.5.3 was revisited. Using the same lookup method outlined previously the replacement factor for each part was matched with

each heroic action. The replacement factor is a figure used by program office analysis to determine the average rate of replacement per aircraft. This is a number between zero and one, with one indicating a need to replace the part for each aircraft that goes through depot.

The heroic actions with a replacement factor greater than 0.8 were removed from the data and the heroic action frequencies were recalculated using the methodology used to establish the baseline model. The revised input is included in Table 7 as an approximation to represent the case where additional funds had been given to DLA and GLSC for ordering and managing part inventories with these extra funds spent on parts with high replacement probabilities. Using the

Table 7: Alternate Scenario Heroic Action Frequency Distributions

	CANN	**AMARG**	**Lateral**	**Emergency Buy**
Process 1	DISC(.48, 0, .77, 1, .86, 2, .98, 3, 1, 4)	DISC(.97, 0, 1,1)	DISC(.85, 0, 1, 1)	DISC(.92, 0, 1, 1)
Process 2	-	-	DISC(.94, 0, 1, 1)	-
Process 3	DISC(.19, 0, .45, 1, .70, 2, .88, 3, .92, 4, .94, 5, 1, 6)	DISC(.97, 0, 1, 1)	DISC(.64, 0, 1, 1)	DISC(.84, 0, 1, 1)
Process 4	DISC(.36, 0, .64, 1, .83, 2, .94, 3, .98, 4, 1, 5)	DISC(.96, 0, 1, 1)	DISC(.91, 0, 1, 1)	DISC(.98, 0, 1, 1)
Process 5	-	DISC(.92, 0, 1,1)	DISC(.62, 0, 1, 1)	DISC(.89, 0, 1, 1)
Process 6	-	-	-	DISC(.98, 0, 1, 1)
DISC – Expression pulls values from a discrete distribution with given parameters				

revised data did change some of the input distributions for the heroic actions, especially depot cannibalization, while others remained unchanged.

3.8 Summary

This section outlined the development of a simulation for the assessment of the impact of heroic actions on depot processes. Discussions with program offices and maintenance wing staff resulted in a conceptual model for the interaction of depot processes and heroic actions. This model was then translated into the Arena simulation software. Data for inclusion in the model was difficult to obtain and was significantly lacking on multiple occasions. The process used for transforming the depot data obtained for this effort into model input was also described in this chapter. Model verification and validation as well as the development of an alternate state of the system were also described. The next chapter discusses the results and analysis of our simulation study.

IV. Results and Analysis

4.1 Overview

This chapter details the results and analysis from the simulation described in Chapter III. The focus of this analysis is to obtain insight into the impact of heroic actions on depot processes in terms of flow days and cost. This section discusses simulation run setup and the process used to determine run setup parameters. Initial results from the baseline model are assessed against summary data from the real system for the rough time frame that the input data was provided from as validation of the model. An analysis of the baseline case and the alternate inventory funding scenario is included. This assessment compares flow days and time delay due to heroic actions.

It is expected that by incorporating the cost of heroic actions into the total cost of chosen inventory levels, that procurement and inventory funding decisions may be managed differently. This section details the estimation of a cost of heroics curve and subsequent comparison with estimated total inventory costs for the KC-135 PDM operations.

4.2 Simulation Run Setup

For this simulation, the steady state statistics were of primary interest. Since the simulation starting state is idle and empty, a warm up period was specified in Arena. To establish a reasonable warm up time, the model was set to run until 300 aircraft had exited the model, and for 10 replications. The Output Analyzer was used to plot KC-135 cycle times by model run time and identify the point where the impact of the model initial conditions visually

appeared to have left the data (see Figure 11). The black line, in Figure 11, at 250 days denotes the point in the simulation where the model output was reasonably distant from the effects of the model's initial conditions.

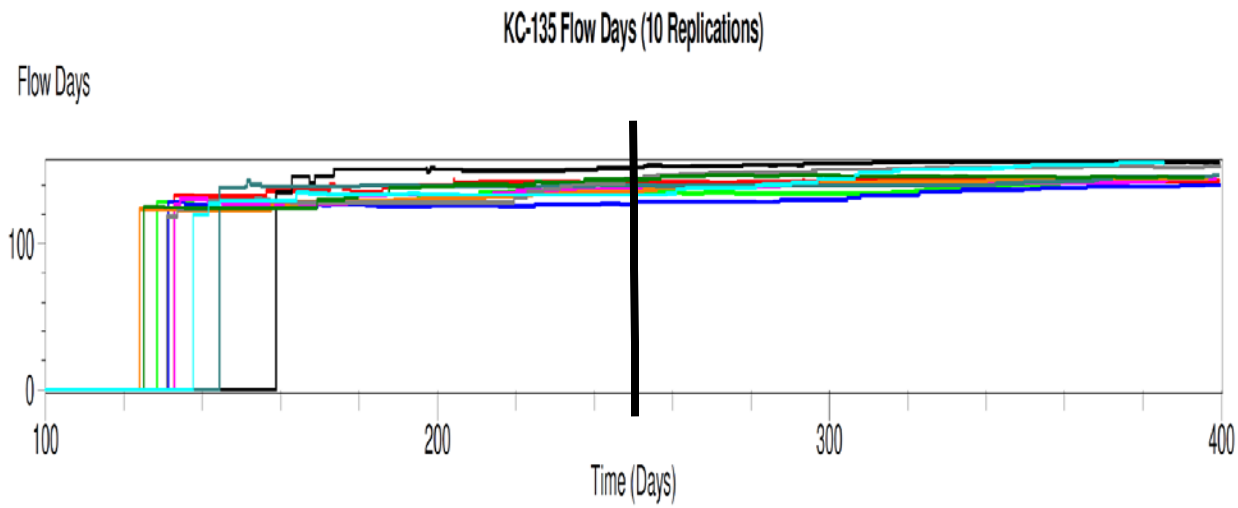

Figure 11: KC-135 Warm Up Period Determination

For the data generation described in subsequent sections the model was run for a total of 510 days, which consists of a 250 day warm up period and a 260 day period used to generate statistics. The 260 day period represents one full year of processing at the depot (five days per week, 52 weeks per year). This time frame was selected to ensure that a reasonable comparison could be made between the model output and data obtained regarding the actual maintenance operations. Fifty replications were executed to obtain the full data set for each scenario. Fifty replications reliably yielded half widths on flow day metrics of one to two days and deemed sufficient for this study. Computational time for this model was negligible, executing all 50 replications within one minute when animation was disabled.

4.3 Validation

Once all input data and model runtime parameters were finalized, statistics were collected for evaluation. Two primary metrics were available for comparing the baseline model against data collected from KC-135 PDM operations; average PDM cycle time (flow days) and the average number of aircraft in process. A summary of these statistics is shown in Table 8. It should also be noted that our model was driven with an aircraft arrival rate of one aircraft every six days based upon subject matter expert input. This equates to 43 arrivals over a year of 260 modeled working days.

Table 8: Validation Statistics

	KC-135 FY11	Baseline Model Average	Baseline Model 95% CI	Model Min	Model Max
Avg. PDM Cycle Time (Days)	159	143	[143.9, 144.1]	142	164
Avg. Number of Aircraft in Process	22	26.20	[25.73, 26.67]	23	30

The model shows an average PDM cycle time of 143 (95% Confidence Interval; [143.9, 144.1]) versus an empirical average cycle time of 159 days, a difference of roughly 16 days. The range covered by the model minimum and maximum average cycle time does include the empirical average. Since four of the eight heroic actions mentioned in section 2.2 are not included in our model this appears reasonable. A less reasonable result would have been that the model cycle time being significantly higher. Other possibilities for mismatch reside with the

assumptions regarding the work content of the base cycle times in the sub processes and lack of empirical data for heroic processes cycle times.

The average number of aircraft in PDM at the depot was 22 in FY11 for the KC-135. The baseline model recorded an average number of aircraft in PDM of 26.20 with a maximum value of 30 and a minimum of 23. The difference in the average values was about 4 aircraft, while the minimum model value was close to the empirically recoded average. The discrepancy in empirical and model values for average number of aircraft in PDM could be due to an inaccurate arrival schedule or an aircraft build up after the SBUP sub process created by a shorter than reality cycle time.

Overall the model represents the real system reasonably well for aircraft cycle time and average number of aircraft in PDM. Although there are differences between the model and real system values, they can be reasonably accounted for given the assumptions and abstractions intentionally included in the simulation. Our simulation provides a top level look at some of the dynamics of KC-135 depot operations and explicitly captures the impact of at least a subset of heroic actions.

4.4 Comparison of Baseline and Alternate State

An alternate scenario was developed and implemented in Arena as described in section 3.8. This scenario represents the occasion where the DLA and GLSC have been given an increased amount of funding for additional inventory or have increased their procurement efficiency. We modeled this increased funding by removing all parts with a replacement factor greater than 0.8 from the data. Using this comparison scenario, the impact of increased funding

for inventory can be assessed. In this section both a direct comparison of the baseline and alternate scenario is presented along with the development of a cost of heroics curve.

4.4.1 Flow Days Comparison

The average PDM cycle time data from both the baseline and alternate model scenarios is shown in Table 9.

Table 9: Baseline and Alternate Scenario Flow Days Comparison

	Avg. PDM Cycle Time (Days)	Mean Difference (Days)	Two Sample Comparison of Means 95% Confidence Interval (Days)
Baseline	143.0	1.6	[1.16, 2.05]
Alternate	141.0		

The alternate scenario generated an average PDM cycle time of 141 days, a difference of 1.6 less flow days on average from the baseline scenario. A two sample comparison of means test was executed on the data obtained from the simulation replications. This test generated a 95% confidence interval on the replication means, shown in Table 9. Since zero difference is not included in the interval, the two samples are statistically different. Thus, being able to successfully procure highly used items (replacement factor greater than 0.8) would reduce flow days by 1.6 days on average. This equates to about 2.2% of the baseline flow days, which may not represent a huge increase in flow day performance, but shop hours lost could be significant. The lost shop hours due to heroics is explored in the next section.

4.4.2 Delay Due to Heroic Action Comparison

The total heroic time and average heroic time per aircraft over the simulation run for the baseline and alternate procurement scenarios are shown in Table 10 and Table 11. The total heroic time is a statistic collected that sums up the time an aircraft spends in delay due to depot cannibalization and waiting on parts to be fulfilled via any of the other three actions across each of the SBUP sub processes. And the average heroic time per aircraft is the total heroic time divided by the number of aircraft through PDM.

Table 10: Baseline and Alternate Scenario Heroic Time Comparison

	Average Total Heroic Time (Hours)	Mean Difference (Hours)	Two Sample Comparison of Means 95% Confidence Interval (Hours)
Baseline	603	394	[326, 462]
Alternate	209		

The baseline scenario generated an average total heroic time across the simulation of 603 hours while the alternate scenario generated a total time of 209 hours. A two sample comparison of means test was executed on the data obtained from the simulation replications. This test generated a 95% confidence interval on the replication means, shown in Table 10. Since zero difference is not included in the interval, the mean total heroic times of the alternate and baseline scenarios are statistically different. Thus, being able to successfully procure highly used items (replacement factor greater than 0.8) would reduce the average time lost because of heroic actions by 394 hours.

Table 11: Average Heroic Time Per Aircraft

	Average Total Heroic Time per Aircraft (Hours)	Mean Difference (Hours)	Two Sample Comparison of Means 95% Confidence Interval (Hours)
Baseline	14.8	6.57	[5.67, 7.46]
Alternate	8.25		

The baseline scenario generated an average total heroic time per aircraft across the simulation of 14.8 hours while the alternate scenario generated a total time of 8.25 hours. A two sample comparison of means test was executed on the data obtained from the simulation replications. This test generated a 95% confidence interval on the replication means, shown in Table 11. Since zero difference is not included in the interval, the mean total heroic times of the alternate and baseline scenarios are statistically different. Thus, being able to successfully procure highly used items (replacement factor greater than 0.8) would reduce the average time lost because of heroic actions by 6.57 hours per aircraft.

4.5 Summary

In this chapter a discussion of simulation run setup parameter settings was discussed. Steady state analysis was executed and a warm up time determined based on average PDM cycle time. Key simulation output was compared to empirical measures of the real system performance. The simulation performed moderately well compared to these indicators and is reasonably suitable for estimation of time lost due to heroic actions. An alternate system was determined to yield statistically different results in terms of average PDM cycle time and total heroic time when compared with the baseline model. The raw data from the alternate and

baseline models was also used to estimate two points on the curve representing the cost of heroic actions.

V. Conclusion

5.1 Overview

This chapter provides commentary on the results presented in our study. The usefulness of the total heroic time comparison and the need for a high level model are discussed. Throughout the course of this effort several areas for further investigation have presented themselves, these opportunities are discussed in this section. The chapter concludes with final remarks on establishing the impact of heroics on depot operations.

5.2 Implications

The analysis presented in section 4.4.2 showed that the total hours lost to heroics was significantly different and less than in the baseline case. This case assumes that supply personnel will spend any additional procurement funds on parts that they know will be needed and spend it on the right parts in the right quantities. A similar result was found when comparing the KC-135 flow days (see section 4.4.1). Further alternate scenarios could be generated to gather more points on the cost of heroics curve for the KC-135.

Determining the impact of less funding for inventory on heroics, using this methodology, would be impossible. However, this approach has enabled a first look at the flow day and man hour impacts of heroics on depot operations. This simulation study has specifically shown that increased funding for spare parts could reduce the impact of heroics. Future efforts to quantify these impacts by AF organizations (AFMC, depots, DLA, GLSC, etc.) could use this methodology, in the current data challenged environment, and gain some insight into heroics.

5.3 Future Work

During this investigation, several areas for further thought and effort have presented themselves. At the depot level, if there is serious interest in addressing the cost and flow day impacts on their operations, the current methods for capturing data when heroic actions occur should be reevaluated. The existing data that was obtained for this simulation study (depot cannibalizations, AMARG pulls, lateral supply and emergency buy) would have been much more useful with the inclusion of aircraft tail numbers, need dates, and consistent use of request/received dates. It also appeared that data regarding field and depot deferral actions as well as any records of depot manufacturing actions is not available in any useful form. Formal processes do exist for managing these types of actions and some data is maintained in a database, but the staff at the depot could not provide any insight into how to obtain these records for analysis. A future effort pertaining to this topic without more data, to echo prior comments, would be (at best) as much art as science.

An interesting future analysis to undertake would be modeling the generation of heroic actions of a handful of parts, explicitly including a procurement process and a production process. The analysis presented in this thesis presents a gross estimate of the labor hours lost due to heroic actions on the depot floor, but this kind of analysis leaves several important questions unanswered, such as; if I have more procurement funds, what parts do I buy?, how much funding does it take to make a significant impact of heroics costs?, or how much of this problem is caused by procurement inefficiencies? A part specific/part family level analysis would be suitable for providing insight into these types of questions.

A large number of parts that generate heroic actions are categorized as low procurement volume, with an average replacement rate of 10% or less. It could be possible that creative procurement practices could minimize the risk of not having a part when you need it, especially for rarely used parts but are known to be needed occasionally. An assessment of the impact of these 'creative' procurement practices would likely be of interest to the depot community.

5.4 Final Summary

This simulation study presents a method for determining the high level impact of heroics on depot operations in terms of flow days and lost labor hours. An alternate procurement scenario was developed and compared to the baseline system. Using this approach the impact of heroic actions could be estimated and a cost of heroics curve could be generated for any AF weapon system or depot. As the depots pursue their own investigation into heroic actions, any new data could be added to the model for increased validity.

Appendix. ENS Quad

Bibliography.

"Bullet Background paper on Cost of Line Stoppage Caused by Parts Shortages." Report to AFMC/A4, Suspense #1341516, Wright-Patterson AFB, OH. October 2011.

Farris, Theresa. "564 AMXS Way Ahead." Organization Overview Briefing, 564th AMXS. Oklahoma City, OK. 12 January 2012.

Fisher, W. W. and Brennan, J. J.. "The Performance of Cannibalization Policies in a Maintenance System with Spares, Repair and Resource Constraints," *Naval Research Logistics Quarterly,* 33: 1-15 (February 1986).

Gehret, Greg. "Bullet Background Paper on AFGLSC 591st (402nd GUSB) Proposed Thesis Topics for AFIT." Report to AFIT Professors, AFIT, Wright-Patterson AFB OH, 26 August 2011.

Gill, Clinton. Chief, 76th MXW Transformation Office, Oklahoma City, OK. Personal Correspondence. December 2011.

Kaminski, Charles. Logistics Management Specialist, KC-135/GKNCA, Oklahoma City, OK. Personal Correspondence. November 2011 - February 2012.

Painter, Michael K., Mayer, Richard J.. *Lean Value Chain (LVC) for Critical Part Procurement.* Final Report. Defence Techincal Information Center. Wright-Patterson AFB OH, August 2002 (ADB288209).

Palacios, Federico. KC-135 Production Support Technician, 564th AMXS/MXDXA, Oklahoma City, OK. Telephone interview: 9 February 2012.

Perez, Angelique. “Joint Bilateral Training.” Excerpt from official US Air Force website. n. pag. http://www.af.mil/photos/media_search.asp?q=angelique&page=1. 27 February 2012.

Rayner, Craig. KC-135 Production Operations, 564th AMXS/MXDPAA, Oklahoma City, OK. Personal Correspondence. January 2012 - February 2012.

Schanz, Marc V.. “More Factory than Flight Line,” *AIR FORCE Magazine*, December 2011; 26-29.

Shyong, Shenn-Rong. *Advanced Planning and Scheduling in the United States Air Force Depot-Level Maintenance.* MS thesis, AFIT/GLM/ENS/02. Graduate School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2002 (ADA400202).

Towell, Joe. Functional Lead, Requirements Integration Process Improvement Team, Wright-Patterson AFB, OH. Personal Correspondence. October 2011.

Yee, Florence K. *Depot-Level Simulation and Multivariate Analysis on B-1 High Velocity Maintenance.* MS thesis, AFIT/OR/MS/ENS/11/26. Graduate School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2011 (ADA541044).

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14. ABSTRACT
This thesis explored the impact of heroic actions on depot maintenance operations in terms of aircraft flow days through programmed depot maintenance and in terms of lost production hours. In an era of fiscal uncertainty and reducing budgets, an understanding of the impact of heroic actions would lead to efficiency gains for the Air Force. Depots do not routinely report the associated impact of heroic actions on their operations and recent efforts to assess these impacts have not arrived to a definitive conclusion.

To assess the impact of heroic actions on depot processes, a discrete event simulation was developed for the KC-135 depot operations and heroic actions. Two scenarios were developed and relative impact of heroics was assessed. A baseline case was created with the intent to model current operations and an alternate scenario was developed based on the premise that additional funds for part procurement would reduce the flow day and production hour impact of heroics. An analysis of these scenarios shows that reducing the frequency of heroic actions does significantly impact KC-135 flow days and lost production hours.

15. SUBJECT TERMS
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